March 18, 1941. A. V. HAEFF 2,235,016

ELECTRON DISCHARGE DEVICE

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Fig. 1

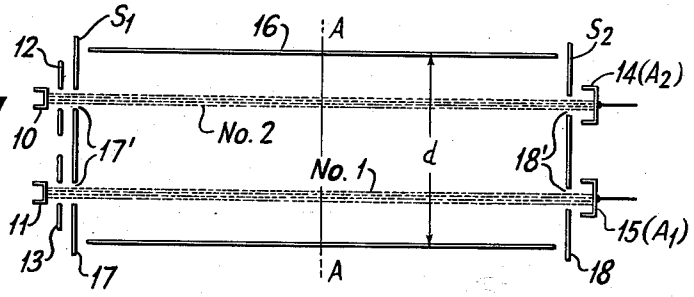


Fig. 2

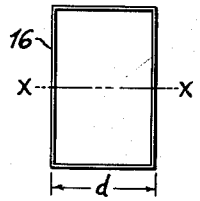


Fig. 3

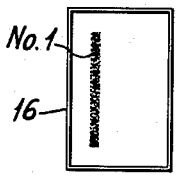


Fig. 4

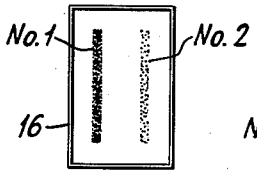


Fig. 5

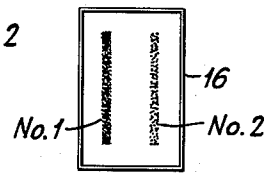


Fig. 2a

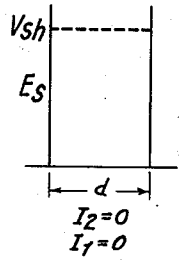


Fig. 3a

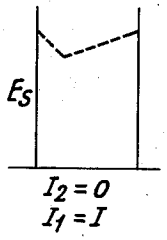


Fig. 4a

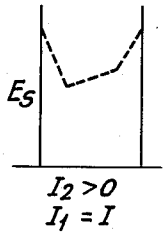


Fig. 5a

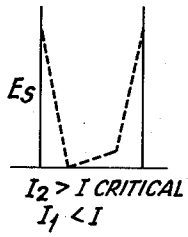


Fig. 6

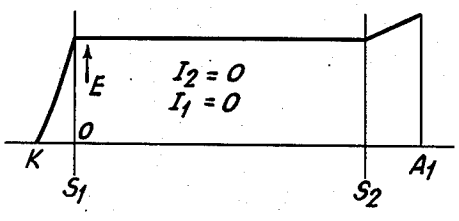
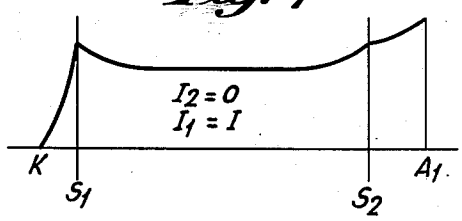


Fig. 7



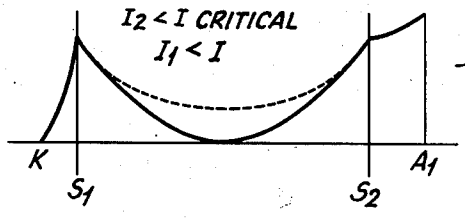


Fig. 8

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Fig. 9

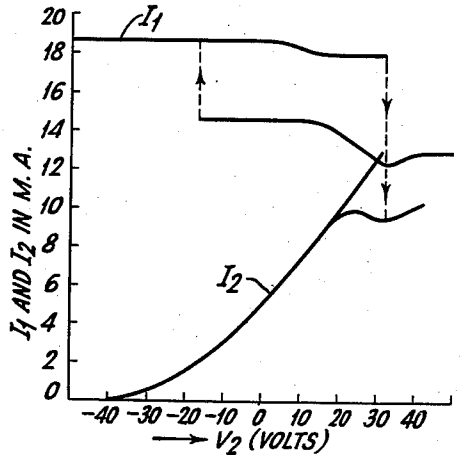


Fig. 10

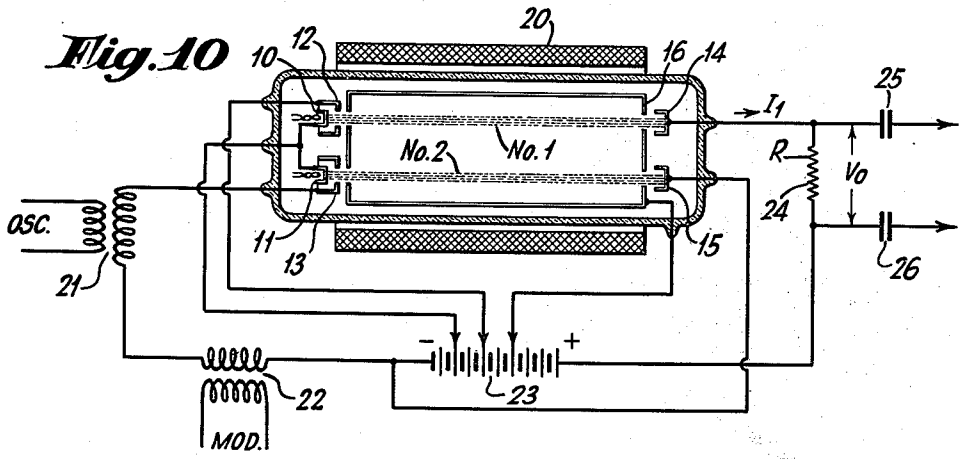


Fig. 12

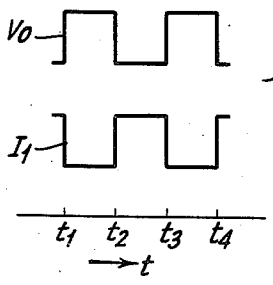
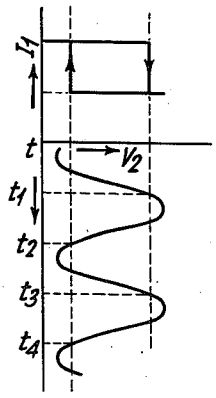


Fig. 11



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ELECTRON DISCHARGE DEVICE

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Application March 10, 1939, Serial No. 260,987

13 Claims. (Cl. 250—27)

My invention relates to electron discharge devices particularly of the beam type utilizing a plurality of beams.

In studying the effects of space charge in electron beams I have found that it is possible to control current in one beam by varying current in the adjacent beam due to the interaction of the space charge fields of the two currents. I have found that tubes of this type have characteristics which make them particularly suitable for use as electronic relays or as generators of square shaped pulses of current or voltage. Such characteristics are highly desirable in tubes intended for certain types of apparatus.

It is the principal object of my invention to provide an electron discharge device of the beam type, particularly such a device utilizing a plurality of beams and in which a control of one beam can be obtained by varying the current in an adjacent beam. More specifically it is an object of my invention to provide such a tube which is capable of use as an electron relay or generator of square shaped pulses of currents or voltages.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims, but the invention itself will best be understood by reference to the following description taken in connection with the accompanying drawings in which Figure 1 is a diagrammatic representation of the electrode arrangement of an electron discharge device made according to my invention, Figures 2 to 5 inclusive show the electron beam and field potential conditions along the plane A—A of Figure 1 for different conditions of current density, Figures 6 to 8 inclusive are diagrams representing the potential distribution along the controlled beam of the tube shown in Figure 1, Figure 9 represents the characteristic curves of a device made according to my invention, Figure 10 is a diagrammatic showing of a tube in section and a circuit made according to my invention for producing square shaped pulses of current and voltage, and Figures 11 and 12 are diagrammatic representations of the current and voltage variations with respect to time of the apparatus shown in Figure 10.

Referring to Figure 1 an electron discharge device made according to my invention comprises at least a pair of cathodes **10** and **11** and the apertured electrodes **12** and **13** for forming the electrons into a plurality of beams which may be received by electrodes **14** (A_2) and **15** (A_1). Positioned between the cathodes **10** and **11** and the electrodes **14** and **15** is a sheath which may be of rectangular cross section and made of sheet metal having at either end the shields **17** and **18** which may also be referred to as shields S_1 and S_2 and which may be mechanically and electrically connected to the ends of the sheath **16**. The shields have apertures **17'** and **18'** registering with each other and with the beams directed from the cathodes to the electrodes **14** and **15**. A solenoid, not shown, may be used for maintaining the beams focussed after they are injected into the sheath **16**. Assuming that the No. 2 beam is the controlling beam and that the No. 1 beam is the controlled beam, the electrode **13** is maintained at some positive potential with respect to the cathode **11**, whereas the apertured electrode **12** may be used as a control electrode and biased to some potential negative with respect to the cathode **10**. The shields **17** and **18** and sheath **16** are biased positively with respect to the cathodes. The electrodes **14** and **15** may be maintained at a still higher positive potential with respect to the cathodes than the shields **17** and **18** and sheath **16**.

Figures 2 to 5 inclusive show the beam and field potential conditions within the sheath under various conditions. The sheath is reduced in size from Figure 1. In Figure 1 with no electrons injected by either cathode into the sheath the entire space within the sheath is at the same potential equal to the voltage on the sheath **16** and shields **17** and **18**. The space potential represented by the dotted line in Figures 2*a*, 3*a*, 4*a* and 5*a* is that measured along the line X—X, see Figure 2, lying in the plane A—A, see Figure 1. The distance *d* is the distance between the sides of the sheath **16**. If now beam No. 1, the controlled beam, is injected into the sheath as shown in Figure 3, the space potential will be depressed as shown in Figure 3*a*, the vertical lines representing the voltage on the sheath and the dotted line representing the potentials at the positions and between the beams. If now beam No. 2 is injected into the sheath, as shown in Figure 4, the space potential distribution will be as indicated in Figure 4*a*. If the current in beam No. 2 is increased by an increase in the voltage on the control electrode **12** to a critical current as indicated in Figure 5, the space potential condition represented in Figure 5*a* will result. At this point the space charge conditions of beam No. 1 become unstable, that is any further increase in current in the No. 2 beam will cause the space potential at beam No. 1 to fall abruptly to zero, which will result in the forma-

tion of a virtual cathode in beam No. 1. Under these conditions part of the current in beam No. 1 instead of proceeding to the collector or output electrode **15** will be reflected from the virtual cathode back towards the cathode. The formation of the virtual cathode in Beam No. 1 may or may not precipitate the formation of the virtual cathode in the controlling beam No. 2 depending upon the proximity of the two beams, their positions with respect to the sheath electrode, and the initial value of the controlled current in the No. 1 beam.

Figures 6 to 8 inclusive show the voltage conditions existing along the longitudinal axis of beam No. 1 under the conditions indicated. It will be seen with no current flowing as shown in Figures 2 and 2*a*, the voltage increases from the cathode to the voltage on the shield remaining constant until the shield S_2 is reached and increasing again to the output electrodes **15**. When beam No. 1 is injected into the sheath as represented in Figure 3 the voltage distribution is as shown in Figure 7, the voltage being depressed as indicated between the screens S_1 and S_2. The voltage distribution with the current conditions shown in Figure 5 is represented by the full heavy line in Figure 8. The potential drops to zero in the case somewhere in the middle of the beam, that is at the position of the virtual cathode. The dotted line shows unstable condition just before the critical value of current in beam No. 2 is reached.

In Figure 9 are shown the current and voltage characteristics of a tube made according to the construction shown in Figure 1 and which were experimentally obtained. The control current I_1 and the controlling current I_2 are shown plotted against the potential V_2 applied to the control grid **12**. As the voltage V_2 is increased the current in the No. 1 beam, that is I_1 remains substantially unchanged at a value of $I_1=18.80$ ma. until the potential $V_2=+32$ volts. At this point, the controlling current I_2 in beam No. 2 increases to a value of $I_2=13$ ma. which is sufficient to cause instability in beam No. 1 so that the current I_1 abruptly decreases to a value of $I_1=12.5$ ma. Both currents remain substantially unchanged with further increase in V_2. This is the condition represented by Figures 5, 5*a* and 8. The controlling current I_2 also changed abruptly at $V_2=32$ volts which indicates the formation of a virtual cathode in both beams at this point. As the voltage V_2 is reduced the virtual cathode disappears in the No. 2 beam at $V_2=20$ volts but in the controlled beam No. 1 it persists until a value of $V_2=-17$ volts and $I_2=1.6$ ma. is reached. At this point I_1 increases abruptly from 14.8 ma. to its original value $I_1=18.8$ ma.

A practical embodiment of my invention was built having the following dimensions. The sheath **16** was 2'' long, 1'' high and .6'' wide. The distance between centers of the cathodes was .4'' and spaced .05'' from the control electrodes **12** and **13**, the spacing between these electrodes and the shield S_1 being .05''. The spacing between the shield S_1 and S_2 and the sheath was .05'' although in practice these could be made integral with the sheath. Each beam had a cross section of approximately .8'' in height by .08'' in width. The apertures in the screens were .12 in width and in the control grid .10'' in width, both being about 1'' in height. The electrodes **14** and **15** were about .10'' from the shield S_2. These apertures of course were in registry with the beams. The following voltages were used. The control grid **12** was maintained at 55 volts positive while the voltage on the control grid was varied from a negative voltage of about −50 volts to a positive voltage of over 30 volts. The voltage on the screens S_1 and S_2 was approximately 100 volts and on the sheath 80 volts although voltages on the screen and shield could be the same. The voltages on the two electrodes A_1 and A_2 were 300 volts. The strength of the magnetic field was 500 gauss. With these applied voltages the characteristic curve shown in Figure 9 was obtained.

The characteristics shown in Figure 9 can be utilized in a tube used as an electronic relay or as a generator of square-shaped pulses of current or voltage.

In Figure 10 is shown a tube made according to my invention and a circuit to be used as a square wave generator. In this figure the beams are shown reversed from that in Figure 1, the No. 2 beam or the controlling beam originating at cathode **11**. In this figure a solenoid **20** is shown, which provides a magnetic field parallel to the axis of the tube to maintain the beams more accurately focused. The control voltage is applied to the control electrode **13** by means of the oscillator input transformer **21**, a second or modulating voltage being applied to the same electrode by the modulating transformer **22**. The control grid **13** is biased negatively with respect to the cathode by means of the voltage source **23**, the apertured electrode **12** being used as a focusing and accelerating electrode by biasing it positively with respect to the cathode **10**. The sheath **16** and end shields are maintained at a still higher positive voltage with respect to the cathode, the output electrode **14** being connected through a load resistor **24** to the most positive part of the voltage source **23**. The condensers **25—26** are coupling condensers for applying the voltage drop V_0 to the input of the succeeding stage. In the arrangement shown the electrode **15** is maintained at a negative potential with respect to the cathode so that the controlling current I_2 is reflected from it and returned to the cathode **11**. This increases the controlling effect of beam No. 2 and at the same time prevents power being wasted by the controlling current.

Reference may be had to Figures 11 and 12 to illustrate the result of the applied voltage V_2 to the electrode **13** and the resulting electronic current I_1 and voltage V_0 across the load R with respect to time. Figure 11 shows the characteristic curve of the current I_1 in beam No. 1 against the voltage V_2 when a sine wave signal V_2 is applied to the controlling electrode **13**. The resulting square wave output electronic current I_1 and the output voltage V_0 across the output resistance is shown in Figure 12. The voltage V_0 can be made to actuate an amplifier. Adjusting the amplitude of the input voltage V_2 or the biasing voltage, or both, on the control grid **13**, it is possible to vary the time intervals t_1—t_2 and t_2—t_3 etc. A transformer **22** actuated by a separate modulating source can be used for continuously modulating the time intervals t_1—t_2, t_2—t_3. The position and the magnitude of the loop on the I_1 against the V_2 characteristic can be varied by the potentials on the sheath electrode and of the control grid **10**. The beams can be focused by a magnetic field parallel to the beam as indicated and be produced either by a solenoid or a hollow cylindrical permanent magnet magnetized in its axial direction.

While I have indicated only two beams as being used in my device it is apparent that three or more could be used and various combinations obtained for controlling one or more beams by one or more controlling beams. While I have shown a complete sheath surrounding the discharge path between the cathodes and anodes, it is of course possible to employ separate plane sheath electrodes positioned on opposite sides of the electron beams to which the same or different potentials could be applied for providing different field gradients from one electrode to the other to vary the characteristics of the tube. These are merely extensions of the broad principles disclosed above.

While I have indicated the preferred embodiments of my invention of which I am now aware and have also indicated only one specific application for which my invention may be employed, it will be apparent that my invention is by no means limited to the exact forms illustrated or the use indicated, but that many variations may be made in the particular structure used and the purpose for which it is employed without departing from the scope of my invention as set forth in the appended claims.

What I claim as new is:

1. An electron discharge device having means for supplying a plurality of parallel adjacent electron beams exposed to each other substantially throughout their length, an output electrode for receiving one of said beams and means for modulating another of said beams to vary the current in said one beam.

2. An electron discharge device having means for supplying a plurality of parallel adjacent electron beams exposed to each other substantially throughout their length, means for inducing a magnetic field parallel to said beams for maintaining said beams focused and parallel, an output electrode for receiving one of said beams, and means for modulating another of said beams to vary the current in said one beam.

3. An electron discharge device having means for supplying a plurality of parallel adjacent electron beams exposed to each other substantially throughout their length, and an output electrode for receiving one of said beams and means for modulating another of said beams to vary the current in said one beam, means adjacent the discharge path of said beams for providing in the absence of said beams an equipotential space between the means for supplying said beams and said output electrode.

4. An electron discharge device having means for supplying a plurality of parallel adjacent electron beams exposed to each other substantially throughout their length, electrodes positioned in registry with said beams for receiving said beams and spaced from said means for supplying said beams, and means for modulating one of said beams to vary the current in another beam.

5. An electron discharge device having means for supplying a plurality of parallel adjacent electron beams exposed to each other substantially throughout their length, an output electrode for receiving one of said beams and means for modulating another of said beams to vary the current in said one beam, means adjacent the discharge path of said beams for providing in the absence of said beams an equipotential space between the means for supplying said beams and said output electrode, and magnetic means for maintaining said beams focused and parallel to each other.

6. An electron discharge device having means for supplying a plurality of parallel adjacent electron beams exposed to each other substantially throughout their length, electrodes in registry with said beams for receiving said beams and spaced from said means for supplying the beams, means comprising a sheath surrounding the discharge path between said means for supplying the plurality of parallel adjacent beams and said electrodes in registry with said beams for providing an equipotential space into which said beams are injected, and means for controlling one of said beams to vary the current in another of said beams.

7. An electron discharge device having means for supplying a plurality of parallel adjacent electron beams exposed to each other substantially throughout their length, electrodes in registry with said beams for receiving said beams and spaced from said means for supplying the beams, means comprising a sheath surrounding the discharge path between said means for supplying the plurality of parallel adjacent beams and said electrodes in registry with said beams for providing an equipotential space into which said beams are injected, means for controlling one of said beams to vary the current in another of said beams, and means for producing a magnetic field within said equipotential space for maintaining said beams focused.

8. An electron discharge device comprising a plurality of cathodes for supplying electrons, means for focusing said electrons into adjacent parallel beams and exposed to each other throughout their length, electrodes in registry with said beams and spaced from said cathodes for receiving said beams, means for providing in the absence of said beams an equipotential space between the cathodes and said electrodes in registry with said beams, said last means having apertures at opposite ends and in registry with said beams, and means for controlling one of said beams to vary current in the other of said beams.

9. An electron discharge device comprising a tubular sheath having closed ends, each end being provided with a plurality of apertures registering with the apertures in the other end, a plurality of cathodes adjacent one end of said sheath in registry with the apertures for injecting electron beams into said sheath through said apertures said beams being exposed to each other substantially throughout their length through said sheath and a plurality of electrodes adjacent the other end of said sheath and registering with the apertures in said other end for receiving said beams, an electrode between one of said cathodes and the adjacent end of said sheath for focusing the electrons through an aperture and a control electrode between another cathode and the adjacent end of the sheath for focusing and controlling a beam from another of said cathodes.

10. An electron discharge device having a plurality of cathodes for supplying a plurality of parallel adjacent electron beams exposed to each other substantially throughout their length, electrodes registering with said beams for receiving said beams and spaced from said cathodes, a control electrode between one of said cathodes and one of said registering electrodes, an input circuit connected between said control electrode and its adjacent cathode, and an output circuit connected between the electrode registering with another of said beams.

11. An electron discharge device having a plu-

rality of cathodes for supplying a plurality of adjacent parallel electron beams, electrodes registering with said beams and spaced from said cathodes for receiving said beams, a control electrode between one of said cathodes and one of said registering electrodes, an input circuit connected between said control electrode and its adjacent cathode to control one of said beams, and an output circuit connected between the electrode registering with another of said beams, and a connection between the electrode registering with the beam controlled by said control electrode for maintaining this registering electrode at a negative potential with respect to the means for supplying the electron beams.

12. An electron discharge device having a plurality of cathodes for supplying a plurality of adjacent parallel electron beams, electrodes registering with and spaced from said cathodes for receiving said beams, means adjacent the discharge path of said beams for providing in the absence of said beams an equipotential space, a control electrode between said last means and one of said cathodes to provide a controlled beam, and an input circuit connected between said control electrode and its adjacent cathode, means for maintaining said equipotential space providing means at a positive potential with respect to said cathode, an output circuit connected to another of the registering electrodes and means for maintaining the electrode registering with the controlled beam at a potential not greater than that of the cathodes.

13. An electron discharge device having a pair of adjacent cathodes for supplying a pair of adjacent beams of electrons, a pair of electrodes registering with said beams for receiving said beams, a sheath surrounding the discharge path of said beams and providing in the absence of said beams a unipotential space through which said beams are injected, apertured electrodes positioned between the cathodes and said sheath, an input circuit connected between one of said apertured electrodes and its adjacent cathode to provide a controlled beam of electrons, a source of voltage, means for applying a voltage to said sheath positive with respect to the cathode voltage, a connection between the source of voltage and the electrode registering with the controlled beam to bias said last electrode negatively with respect to said cathode, and an output circuit including a load resistor connected between the other registering electrode and the positive side of said source of voltage.

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